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Title: Wind Loading Analysis of the EdotX Rooftop Sensor

Author(s): Ho, Cheng
Hill, Dallas Dwight
Salazar, Steven Don

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Wind Loading Analysis of the EdotX Rooftop Sensor

Cheng Ho, Dallas Hill and Stephen Salazar
Los Alamos National Laboratory
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1. Executive Summary

We performed a study of the wind loading performance of the EdotX's rooftop sensor design. Two failure modes were examined for the requirement to withstand 100 mph wind:

1. bending/yielding of the antenna mast at the maximum stress point, and
2. tipping over of the base.

Based on the calculation in the Appendix, the yield strength failure at the mast's maximum stress point occurs at 170 mph (70% margin). Currently specified ballast of 12 bricks can withstand 113 mph wind (13% margin) before tipping over. Thirty percent (30%) margin can be achieved by using a ballast of 16 bricks.

2. EdotX Antenna Mount Overview

Figure 1. Left panel: EdotX's sensor mount on the ground. The person in the picture is about 6' tall. Right panel: EdotX sensor in a typical installation on the roof.

EdotX sensor deploys RF antennas at high locations, such as rooftop, to measure transient signals. Figure 1 shows the complete antenna setup, made up of three major components: sensor assembly at the top, sensor mast from top to bottom, and the Commercial-off-the-Shelf (COTS) non-penetrating mount at the bottom. It is installed on a flat roof with ballast at the base. It is required that this free-standing sensor mounting design be able to withstand 100 mph wind. This report provides calculations of the EdotX sensor's wind loading and response, detailed in the Appendix. Per the Appendix, the EdotX baseline sensor design can withstand 100 mph with a margin of 13%, with a low cost path to increase the margin to 30%.

Appendix: EdotX Rooftop Sensor Wind Loading Calculation

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1.0 Purpose

Evaluate the strength of the ISR antenna assembly for sustaining a 100 mph wind load.

2.0 Methodology

Determine the wind load using guidance from an architectural standard design for flagpoles and antenna stress distribution using finite element analysis.

3.0 Acceptance Criteria

The maximum stress in the antenna mast is less than yield stress for the maximum wind load.

4.0 Open Items

None

5.0 Assumptions

None

6.0 Limitations

None

7.0 Calculation Inputs

Required minimum wind speed is 100 MPH

The antenna mast is made of a 60 in length of 2.375" Dia 0.123" wall tube and a nested 10 ft length of 1.5" schedule 40 pipe with 2 sensors on a base mounted on top.

The pipe is supported in a Commscope RM-SM238-60 mount

The OEM Commscope tube is A500 grade C steel with a yield strength of 46 Ksi. The 1.5" schedule 40 pipe, ASTM A570 is mild steel, grade 30, with a yield strength of 30 Ksi .

8.0 Computer Hardware and Software

Mathcad [4] and ANSYS [2]

9.0 Summary and Conclusions

The maximum stress in the antenna assembly is around the 4 bolts holes and is 1/3 (15 Ksi) of the yield strength (45 Ksi) of the A500 steel in a 100 mph wind load. A 170 mph wind will result in the maximum stress being at the yield strength of the tube. The required weight of the ballast is 253 lbf to anchor the antenna assembly in a 100 mph wind. Twelve cement blocks (27 lbf) will support a 113 mph wind and 16 blocks will support a 130 mph wind.

10.0 References

10.1 National Association of Architectural Metal Manufactures, Guide Specifications For Design of Metal Flagpoles, ANSI/NAMM FP 1001-07 8d.

10.2 ANSYS Workbench Version 15.0.0

10.3 Mathcad 15.0, Parametric Technology Corporation.

11.0 CALCULATION

11.1 INTRODUCTION

The wind load on the ISR antenna assembly is determined using guidance from the architectural standard for design of metal flagpoles[1]. A finite element model[2] of the mast is used to determine the stress distribution in the pipe. The goal of the antenna design is to withstand a wind speed of 100 mph without failure.

11.2 DISCRIPTION

The ISR antenna assembly consists of a 1. 5” 10 ft. schedule 40 pipe, Commscope base, and 2 sensors and base mounted on top. The base is a 3 ft square frame with the mast mounting at the center of the square. The 1.5” pipe is 1.9” OD with .145” wall and the base tube is 2.375” OD with .123” wall. The pipe is made of ASTM A570 grade 30 mild steel tubing. The pipe is inset in the base tube for a mast height of 156”. The base tube has 4-3/8” dia through holes evenly spaced 360 degrees around and 30” above the base where support arms are connected. The largest bending moment and stress in the pipe is located in the region of the holes. This baseline configuration is free-standing and held down with ballast. This configuration does not utilize guy wires.

11.3 CALCULATIONS

MAST STRENGTH

The wind load is determined using the architectural standard for design of metal flagpoles[1]. A simple formula using the wind speed and drag coefficient determines the pressure load. The force on the mast is then determined from the pressure load and frontal area of the antenna. This calculation is listed below.

Wind pressure equation

P=.00256 * V^2 * Cd * Ch * G — equation 1, ANSI/NAAMM FP 1001-07 8d

where

$Cd := 1.1$ — Drag Coefficient table 3.2.4

$V := 100$ — Wind speed mph

$Ch := .86$ — coefficient for height above ground for wind pressure table 3.2.3A

$G := 1.14$ — gust effect

$P := .00256 \cdot V^2 \cdot Cd \cdot Ch \cdot G = 27.608$ — Wind Pressure lbf/ft^2

$A_p := \frac{(2.375 \cdot 60.25 + 1.9 \cdot 96)}{144} + \frac{66.9}{144} = 2.725$ — Projected area of antenna asembly including both masts, bracket, and both antennas (from solidworks), ft^2

$F := P \cdot A_p = 75.231$ — Wind force on mast, lbf

The force on the 13 ft antenna assembly at 100 mph wind speed is 75 lbf. This value is converted to a surface pressure in the FEA model and used as the wind load. In Fig. 1 the von-Mises stress distribution is shown for the pipe section. The maximum non-local stress around the 2 bolt holes is at 15 Ksi which is 1/3 the yield stress of the Comscope base tube. The maximum stress in the 1.5" pipe is 8 ksi. The rest of the pipe section is at a lower stress. This antenna configuration will be at yield stress in a 170 mph wind. The top of the antenna assembly will deflect 1.5" in a 100 mph wind.

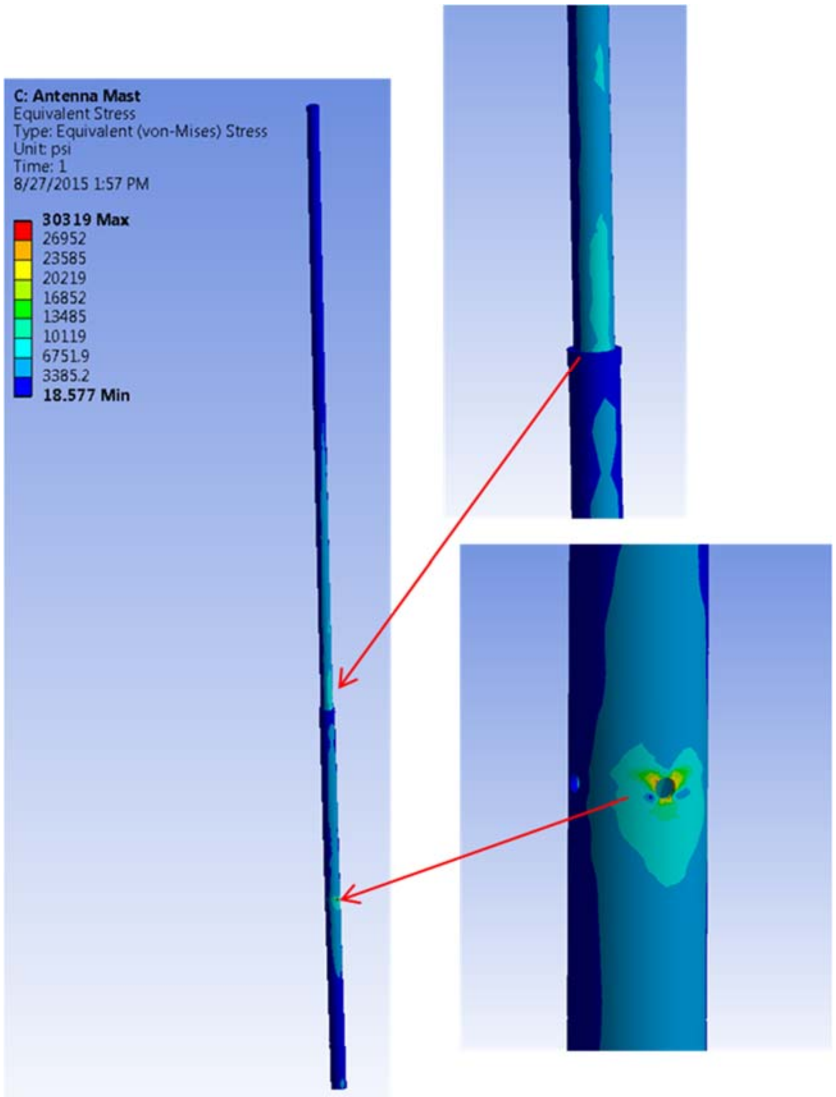

Fig. 1 von-Mises stress distribution in the mast assembly and around the bolt holes

TIP OVER CALCULATION

The mast is anchored to the ground using ballast weight placed on the Commscope base. The base is a 3 ft square angle iron assembly with the mast mounted in the center. The antenna assembly will tip over when the sum of moments is equal to zero on the edge of the base. Using the wind force calculated above and the dimensions of the mast and base the required amount of ballast weight can be determined. A simple sketch of the force diagram is shown in Fig. 2.

$W_{antenna} := 66$ Antenna weight , lbf

$F_{wind} := 75.2$ Wind Force, lbf

$L_{wind} := \frac{76.5}{12} = 6.375$ Distance wind force is from o, ft

$L_{ballast} := 1.5$ Distance ballast force is from o, ft

Σmoments about origin=0

$(W_{antenna}+W_{ballast}) * L_{ballast} = F_{wind} * L_{wind}$

$W_{ballast} := \frac{(F_{wind} \cdot L_{wind})}{L_{ballast}} - W_{antenna} = 253.6$ Ballast weight, lbf

The required ballast is 254 lbf to anchor the antenna assembly in a 100 mph wind. The ballast is made of several 27 lb concrete blocks. Typically, 12 and 16 blocks are stacked on the base which will support a 113 mph and 130 mph wind respectively.

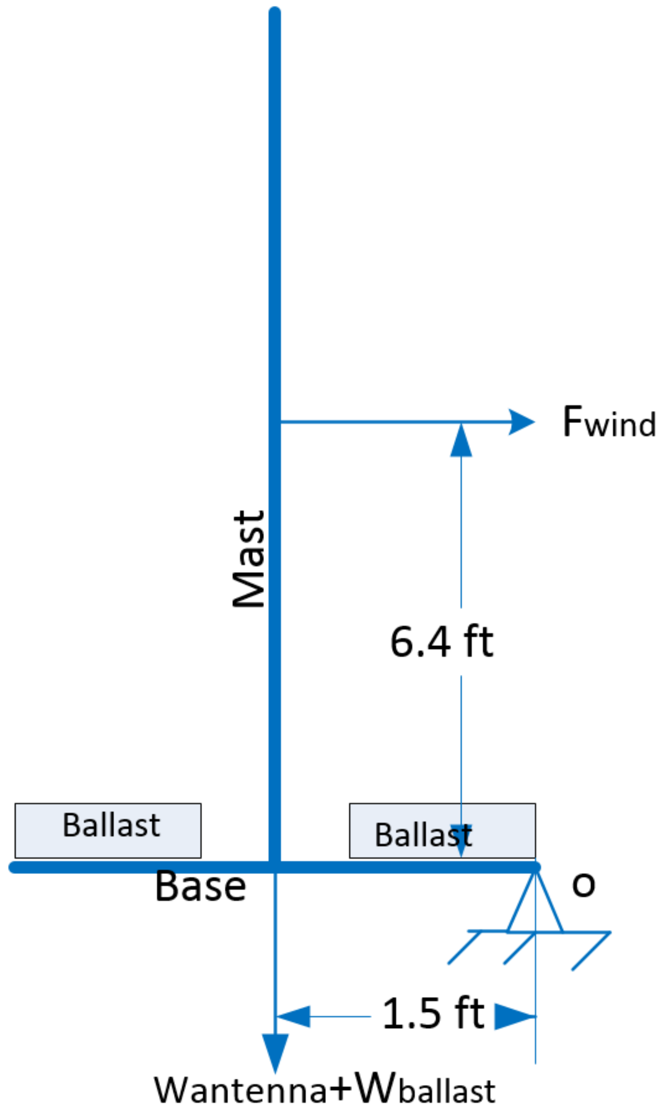

Fig. 2   Sketch of force balance on antenna assembly.

12.0 CONCLUSIONS

The load on the antenna assembly in a 100 mph wind is determined using an architectural standard for designing flagpoles. A structural finite element analysis is performed to determine the stress distribution in the mast. The maximum stress around the 4 support holes is 15 Ksi or 1/3 of the yield strength of the A500 steel. A wind speed of 170 mph will result in the stress being at the yield strength of the steel. The required weight of ballast is 254 lbf to anchor the antenna assembly in a 100 mph wind.

Twelve cement blocks will support a 113 mph wind and 16 blocks will support a 130 mph wind.